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Evaluation of utility of aerial overflight based estimates versus mark-recapture estimates of chinook salmon escapement to the Nicola River, B.C.

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Abstract

We surveyed adult chinook salmon (*Oncorhynchus tshawytscha)* in the Nicola River from a helicopter and examined our count data to determine their statistical properties. Replicated counts were compared and variances estimated for reach counts using regression and quartile approaches. Reach counts were highly repeatable. Expansions of peak counts indexed abundance well among years, however, when using the standard expansion factor (π=1.538), estimates were biased low for three of four years when compared to Petersen mark-recapture estimates. AUC (area-under-the curve) estimates of spawner-days described the spawner abundance in a more robust manner than peak counts. Apparent redd residence times were stable among years (mean = 5.81 d, range 5.34 – 6.37 d). Retrospective AUC estimates, calculated using observed spawner data and the mean apparent redd residence time, adequately estimated spawner abundances for all four years. While at this time, we are unsure of the minimum number of overflights required to produce scientifically defensible AUC escapement estimates, it is likely that four or more flights may be required on many systems. We recommend similar studies be conducted in other watersheds in order to examine: 1) The repeatability of aerial counts; 2) spatial and temporal variability in survey life; and 3) degree of bias associated with aerial overflight-based estimates.

Résumé

Nous avons dénombré les saumons quinnats adultes (*Oncorhynchus tshawytscha)* dans Nicola River à partir d'un hélicoptère, puis nous avons examiné nos données pour en déterminer les propriétés statistiques. Nous avons comparé les dénombrements répétés et estimé la variance des dénombrements par tronçon à l'aide des analyses de régression et par quartiles. L'extension des dénombrements maximaux donnait un bon indice de l'abondance chaque année; par contre, pour trois des quatre années de l'étude, les estimations obtenues en appliquant le facteur d'extension standard (π=1.538) étaient inférieures aux valeurs calculées à partir de données de marquage-recapture selon la méthode de Petersen. Les jours-géniteurs estimés par la surface sous la courbe décrivent mieux l'abondance des géniteurs que ne le font les dénombrements maximaux. Les temps de séjour apparent dans les nids de fraie étaient stables d'une année à l'autre (moyenne = 5,81 jours; étendue : de 5,34 à 6,37 jours). Pour les quatre années de l'étude, l'abondance des géniteurs estimée rétrospectivement par la surface sous la courbe à partir des données sur les géniteurs observés et le temps moyen de séjour apparent dans les nids de fraie était satisfaisante. Bien que nous soyons actuellement incertains du nombre minimal de dénombrements aériens nécessaires pour obtenir des estimations scientifiquement valables de l'échappée en calculant la surface sous la courbe, il faudra sans doute effectuer au moins quatre survols pour de nombreux systèmes fluviaux. Nous recommandons que des études semblables soient réalisées dans d'autres bassins versants pour étudier : 1) la répétabilité des dénombrements aériens; 2) la variabilité spatiale et temporelle pendant la durée des relevés; 3) l'erreur systématique des estimations obtenues à partir de dénombrements aériens.

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1. Introduction

Spawning escapements of spring and summer run chinook salmon (*Oncorhynchus tshawytscha)* to many tributaries of the Fraser River are estimated annually with aerial and mark-recapture methods. In many tributaries upstream of Hells Gate, aerial survey methods have been preferred because of the ability to fly geographically widespread areas in a relatively short time period, the difficulty of accessing many of the systems by land, and since water clarity is appropriate for fish counting from the air. Typically, aerial escapement estimates have been derived from two or three overflights, attempting to count the fish near the peak of spawning activity. At this time, few fish are schooled or holding in pools, and most are on or in the vicinity of the spawning grounds (typically shallower runs and tail-outs). Estimates are typically derived with the assumption that at the peak of spawning, and under ideal conditions, surveyors would observe 65% of the total run (Farwell et al. 1999).

Spawning escapements to selected Fraser River tributaries have been estimated by the Petersen mark-recapture method. This method has the advantage of determining confidence limits for the population estimate. Mark-recapture has been employed to estimate chinook escapements to the Harrison River since 1984 (Farwell et al. 2000), and the Lower Shuswap River in 1984 (unpublished data). The Nicola River spawning escapement was first estimated using mark-recapture in 1995 (Farwell et al. 1999). In this report, since 1995 was a prototype year and field effort was less intensive, we treat 1995 data separately.

To date, little information exists on the repeatability of aerial counts, or the influence of the number and timing of flights, and there are few comparisons of aerial counts against estimates with known statistical properties (fences or mark-recapture studies). The Nicola River chinook program was implemented to permit the examination of aerial count data, and to compare expanded peak count estimates and Area-Under-the-Curve (AUC) estimates with intensive mark-recapture escapement estimates.

The purpose of this report is to provide an overview of the Nicola River program, summarize and compare the resultant escapement estimates (mark-recapture, peak count and AUC), compare the estimation procedures, and consider the applicability of these estimation techniques to other Fraser River chinook stocks.

2. Study Area

The upper Nicola River originates between the Nicola Plateau and the Douglas Plateau, approximately 70 km east of the community of Merritt. It flows in a northerly direction for 97 km before entering Nicola Lake near the mid-point of the south-eastern shoreline of the lake. The Nicola River drains Nicola Lake at a flow control structure, and flows in a south-westerly direction for 12 km before its confluence with the Coldwater River in Merritt. From there, the Nicola River flows in a north-north-westerly direction for 20 km until its confluence with Spius Creek. Below its confluence with Spius Creek, the Nicola flows north-westerly for 52 km, entering the Thompson River at Spences Bridge (Figure 2.1).

The mainstem Nicola River and a major tributary, Coldwater River, are heavily impacted by agricultural practices. Channel bank erosion and widening along with bed destabilization and siltation are common features of the Nicola drainage, often associated with the removal of riparian vegetation to increase grazing land. Other agricultural impacts include channel de-watering due to irrigation and nutrient additions from livestock.

Rood and Hamilton (1995) documented the hydrology of the Nicola basin and reported mean annual daily flows of 22.7 m^3sec^{-1}, mean August flows of 15.9 m^3sec^{-1}. Maximum flows typically occur during May or June, but also may occur when heavy rain and/or sudden warming causes rapid snowmelt in late fall or early spring. Minimum flows often occur in late August or early September. Water temperatures range from 0°C with ice cover in mid winter to as high as 29°C when extreme heat waves are combined with low flows (Walthers and Nener 1997).

Salmonid fish species inhabiting the Nicola River include chinook salmon, coho salmon *O. kisutch*, pink salmon *O. gorbuscha*, steelhead and rainbow trout *O. mykiss*, and bull trout *Salvelinus confluentus*. Non-salmonids include bridgelip suckers *Catostomus columbianus*, sculpins *Cottus* spp., and northern pikeminnow (northern squawfish) *Ptychocheilus oregonensis*.

For the purposes of the analyses, the river and its major tributaries (Coldwater River and Spius Creek) were divided into seven sampling strata (reaches). After 1995, additional information was obtained on the distribution of spawners and an eighth reach was added (Nicola downstream of the Lower Dot Trestle), and reach 3 was expanded upstream to include the Coldwater River downstream of Midday Creek (Table 2.1).

3. Field Methods

3.1 Mark-Recapture Studies

3.1.1 Tag Application

Chinook were captured by angling between early August and early September annually. Capture and marking were attempted in the river segments known to be utilized by pre-spawning chinook. Anglers used single barbless hooks (Eagle Claw L183F) of sizes 1 or 1/0 baited with salmon eggs treated with

borax. Chinook were landed and either processed immediately, or held for up to 30 min in 1.25 m x 0.3 m diameter vinyl flow-through holding tubes, anchored instream in a manner to permit suitable water flow prior to processing. Anglers recorded the relative amount of bleeding from the area of the hook as none, slight, moderate, or heavy and also noted where the fish was hooked. The hooking location was later categorized as either critical (roof of mouth, gills, tongue, or eye) or non-critical.

For tag application, each fish was placed in a canvas cradle in shallow river water. During processing, the fork length was measured (± 1 cm) and the sex and adipose fin clip status recorded. Fish were tagged with Petersen disk tags (except 300 fish in 1995 that were tagged with Ketchum No. 1 Operculum tags). Sex specific operculum punches (one 0.7 cm hole in males and two in females) were applied to the left operculum as a secondary mark prior to release of the fish. The release condition of the fish was categorized as 1 (swam away rapidly), 2 (swam away slowly), or 3 (required ventilation).

3.1.2 Carcass Recovery

Sampling chinook carcasses commenced typically at the onset of spawning and continued until no further carcasses were found. Reaches 2-7 were surveyed in their entirety at least once every five days during the period of the recovery; reaches 1 and 8 were not surveyed consistently. Reach 1 was only surveyed in 1999; a fence operated by the Upper Nicola Indian Band just upstream of Nicola Lake recorded the passage of any adult chinook and their mark status in previous years. Reach 8, the lowest segment of the Nicola River, was excluded because of extremely low densities of fish (typically <20 fish/km). Crews consisted of two to five people, and all surveys were conducted in a downstream direction.

All carcasses were recorded by date, reach, sex (confirmed by incision), tag presence and number, adipose fin clip presence, post-orbital to hypural plate (POH) length (± 1 cm), and secondary mark status. Once sampled, all carcasses were cut in two and returned to the river. Heads were collected from adipose fin clipped (AFC) chinook for coded wire tag (CWT) recovery and decoding. Scale samples were taken from each secondarily marked fish, each fish sampled for CWT recovery, and every tenth unmarked fish not sampled for CWT recovery. Fish were aged according to the Gilbert Rich coding system. The condition of the adipose fin clip was recorded as either complete (flush with dorsal surface), partial (nub present), or questionable (appeared to be clipped but fungus or decomposition obscured the area). The condition of the carcass was recorded as either fresh (gills red or mottled); moderately fresh (gills white but flesh still firm); moderately rotten (body intact but soft) or rotten (skin and bones remaining). The number of eyes remaining in the carcass was also recorded. Apparent spawning success was estimated for all intact female carcasses. Success was categorized as either 0% (pre-spawning mortality), 50% (partially spent), or 100% (virtually no eggs remaining).

3.2 Aerial Enumeration

Aerial counts were performed during low level (10-30 M) flights in a Bell 206B helicopter, at speeds between 10 and 40 $km.h^{-1}$, proceeding downstream. Two experienced observers, each equipped with polarized glasses, seated on the opposite side of the aircraft to the pilot, counted all chinook salmon observed, and recorded them by reach. After the second flight in 1996, live fish were counted in two

categories: actively spawning in an area containing redds, or holding away from spawning areas. Where carcasses had been cut in two by the mark-recovery crew, only posterior sections including tails were counted as a carcass.

During and at the end of each reach count, the observers discussed their observations, recorded their individual tallies, and reached a consensus on the best count for the reach. Frequently, but not always, the best count was the higher count of the two observers' observations. Occasionally, the best count was higher than either observer's individual tally, due to one observer seeing fish that the other failed to see and vice-versa.

For 1995, only two flights were scheduled; one prior to and one to coincide with the expected peak of spawning activity. For 1996 to 1999 we scheduled flights on five days over the period of the spawning migration, typically starting on September 5th and ending on September 18th or 19th. In 1996, the September 15th flight was cancelled due to poor weather, and our last flight was on September 23rd. In 1998, due to very low numbers of fish, and low water causing fish to hold off the river mouth, we had a sixth flight on September 23rd.

3.2.1 Replicate flights

Replicate flights were conducted to determine the repeatability of counts within reaches. Two helicopters, each with experienced counting crews, counted the entire survey area, starting and finishing at approximately the same time. Individual reaches were flown in a different order by the two crews to allow at least one hour between counts. Flight one always started at reach two (immediately below Nicola Lake), and flight 2 usually started at reach four (the confluence of the Nicola River and Coldwater River).

For 1996 to 1999 we scheduled two flights near the peak of spawning (September 12th) to be replicated. In 1996, we were unable to fly on September 15th due to poor weather, so the second replicate flight occurred September 18th. Replicate flights were not conducted in 1998 due to very low numbers of fish, low water causing fish to hold off the river mouth, and accordingly a need to conserve budgets to allow greater temporal representation.

4. Analytic Procedures

4.1 Mark-Recapture Analyses

Mark-recapture data were analyzed as reported in Farwell et al. (1999). Data were assessed for temporal, spatial, size, sex and tagging stress related biases, and the annual adult chinook salmon populations within the Nicola River study area were estimated with Chapman's modification of the Petersen estimator (Ricker 1975). In anticipation of significant sex related differences in the data and in order to facilitate comparison with past or similar studies, the escapement was calculated by sex. The

escapement to the river ($\hat{N}_{i,MR}$) was the sum of the male ($\hat{N}_m$) and female ($\hat{N}_f$) escapements in year *i*. Male escapement was estimated by:

$$\hat{N}_m = \frac{(M_m + 1)(n_m + 1)}{(m_m + 1)} - 1 \qquad (1)$$

where:

M_m = number of males released with primary and secondary marks corrected for sex identification errors

m_m = number of primary and/or secondary marked male carcasses recovered; and

n_m = number of male carcasses examined for marks.

Standard error (square root of the variance) of the male escapement estimate was calculated as:

$$SE_m = \sqrt{\frac{(N_m^2)(n_m - m_m)}{(n_m + 1)(m_m + 2)}} \qquad (2)$$

and 95% upper and lower confidence limits on the male estimate were calculated with the normal approximation. The female spawning escapement ($\hat{N}_f$) and confidence limits were calculated in an analogous manner. Confidence limits for the total escapement were calculated from the square root of the summed male and female variances.

4.1.1 Sex Identification Correction

Identification errors occurred because sexually dimorphic traits were not fully developed at the time of marking and internal examinations were not possible until the carcass survey. Tag application data were corrected for sex identification error with the method described by Staley (1990).

4.2 Aerial Escapement

4.2.1 Area-Under the Curve (AUC).

For each day flown, on each year from 1996 forward, counts of spawning fish were used to construct AUC estimates of the total number of spawner-days that year. For all years, the first fish to be observed on-redd, were seen on 1st September, and for all years except 1998, we assumed the last spawners died on September 30th. In 1998, the last fish died on the 5th of October, thus we used that date for the end point of our AUC.

AUCs were calculated as follows (Irvine et al. 1992):

$$\hat{A} = 0.5 \bullet \sum_{j=2}^{n} (t_j - t_{j-1}) \bullet (p_j + p_{j-1}) \qquad (3)$$

where t_j is the number of days since the first fish commenced spawning, n is the number of overflight surveys + 2, and p_j = estimated number of spawning salmon on the j^{th} day (sum of the reach by reach counts of spawners). Surveys were temporally bounded by the day the first fish commenced spawning (j=1, p_j =0) and the first day it was assumed there were no longer any live spawners remaining (t_n,

where p_n =0). Note that t_j =1 and p_j =0 for the day when the first fish commenced spawning and t_n is the number of days that live spawners are present; thus p_n =0.

Estimates of escapement were calculated by dividing the AUC estimate of spawner-days by an estimate of the average amount of time fish spent on redds ("redd residence time").

4.2.2 Replicated flights.

To assess the repeatability of aerial spawner counts we calculated the intraclass correlation coefficient (Sokal and Rohlf 1981), indicating the proportion of the variation in the data occurring among replicate counts (Krebs 1989). The intraclass correlation coefficient ranges from 0 to 1 with values near 1 indicating little variation within replicate counts and highly repeatable measurements (Krebs 1989).

The variance of the area under the curve (AUC) could not be calculated directly because replicate flights did not occur on all survey dates; therefore the variance of AUC was estimated with a parametric bootstrap procedure. A bootstrap sample was built by randomly drawing one spawner count from an empirical distribution for each daily reach count. The empirical distribution of each daily reach count was assumed to follow a normal distribution with a mean equal to the observed count and a standard deviation (SD) estimated from relationships derived from the replicate counts and their parameters (mean, SD, and coefficient of variation (CV); Appendix 1). AUC ($\hat{A}^*$) was calculated for each bootstrap sample and the procedure was repeated 1,000 times, creating the empirical distribution $\hat{F}(\hat{A}^*)$, which was an estimate of $F(\hat{A})$.

Three parametric bootstrap approaches were used to estimate variance. In the first, AUC was calculated as described above and variance was estimated from Equation 4, where B was the number of bootstrap samples (approach 1).

$$v(\hat{A}^*) = (B-1)^{-1} \sum_{b=1}^{B} (\hat{A}^*_{(b)} - \overline{\hat{A}}^*)^2 \qquad (4)$$

In addition, AUC and variance were estimated for each reach and summed to estimate the total AUC and variance (approach 2). Finally, empirical distributions were developed for the total daily counts by summing the reach counts and their estimated variance, then the parametric bootstrap procedure was repeated (approach 3). For each approach, statistical bias was the difference between the mean of the bootstrap estimates ($\overline{\hat{A}}^*$) and the AUC estimate ($\hat{A}$) expressed as a percentage of $\hat{A}$.

We compared two procedures for estimating the SD of reach counts to provide alternate estimates of the AUC variance (Appendix 1). The first estimated the SD of reach counts from the linear relationship between SD and mean count derived from the replicate reach counts. An analysis of covariance was used to assess the temporal and spatial influence on the relationship. The second procedure estimated the SD of reach counts from the median CV for quartiles of mean counts. We determined quartiles by numerically ordering the mean counts and partitioning them into four groups of equal sizes where the first quartile contained the first 25% of the measurements. The relationship between CV and mean count

indicated high variability for CVs at low spawner counts. Accordingly, we partitioned the mean spawner counts into quartiles and the median CV of the quartile was used to calculate the SD of spawner counts.

4.2.3 Apparent Redd Residence

We estimated the annual apparent redd residence ($\hat{S}_i$) from the mark-recapture spawner abundance estimates ($\hat{N}_{i,MR}$) and the AUC estimates ($\hat{A}_i$) from concurrent sampling programs in year i (Equation 7; Table 4.1). Variance of the annual apparent redd residence was estimated following the method for the division of two independent variables (Equation 8; CTC 1999). The variance of AUC was estimated from the parametric bootstrap procedure with approach 1 and the SD of reach counts estimated from the median CV of quartiles (Appendix 1). The mean apparent redd residence and variance were estimated from the annual apparent redd residence estimates (Equations 7-12), and could be used to estimate escapement in future years (Equations 5 and 6). Approximate 95% confidence intervals were calculated with the normal approximation. In addition, we developed a least squares estimate for apparent redd residence (Hilborn and Walters 1992), with the 1996 to 1999 data.

We calculated retrospective escapement estimates and variance from the mean (over the four years) apparent redd residence and annual AUC estimates (Equations 5 and 6). This was done to confirm that the resultant estimates of escapement did indeed fall within the 95% confidence bounds of the mark-recapture estimate.

4.2.4 Peak live and dead expansion.

When counting conditions were optimal, estimates of escapement were derived by summing the best reach specific counts of live and dead fish observed to obtain a best total daily count. The best total daily count that occurred closest to the peak of spawning (comparatively few holding fish or carcasses; most of the fish actively spawning) was then multiplied by the expansion factor (π) to produce an estimate of the spawning escapement (Equations 13-15; Table 4.2; Farwell et al. 1999). The variance of the annual spawning escapement was estimated from the expansion factor and the variance of the peak count (Equation 14), and approximate 95% confidence intervals were calculated with the normal approximation.

Variance of the peak count was estimated with a modification of the parametric bootstrap procedure for the AUC. Peak count was the sum of spawners, holding fish, and carcasses, thus separate variance estimates were calculated for each parameter and summed to estimate the variance of the peak count. For spawners, a bootstrap sample was built by randomly drawing one count from the empirical distribution of each reach count, which were summed to estimate peak daily count ($\hat{P}_S^*$). Empirical distributions of reach counts were developed with the methods described for the AUC with the SD estimated from the median CV of quartiles (Appendix 1). The procedure was repeated 1,000 times, creating the empirical distribution $\hat{F}(\hat{P}_S^*)$, which was an estimate of $F(\hat{P}_S)$. Variance was estimated from Equation 4 by substituting $\hat{P}_S^*$ for $\hat{A}^*$ and $\overline{\hat{P}}_S^*$ for $\overline{\hat{A}}^*$. The parametric bootstrap procedure was

repeated for holding fish ($\hat{P}_H^*$) and carcass ($\hat{P}_C^*$) counts with the SD of reach counts estimated from the median CV of quartiles (Appendix 1).

We compared mark-recapture ($\hat{N}_{i,MR}$) and peak count ($\hat{N}_{i,PK}$) escapement estimates with the goodness-of-fit method in years with concurrent sampling programs (Seber 1982; Equation 16; Table 4.2). In addition, we calculated the annual relative bias (*RB*) of the peak count expansion estimate with respect to the mark-recapture estimate (Equation 17). The peak count expansion factor was considered virtually constant based on its historic application for Upper Fraser River chinook counts. The variance of the peak count escapement estimate was calculated with Equation 14 (CTC 1999).

We estimated the annual expansion factor ($\hat{\pi}_i$) from the mark-recapture spawner abundance estimates ($\hat{N}_{i,MR}$) and peak count ($\hat{P}_i$) from concurrent sampling programs in year *i* (Equation 20; Table 4.3). Variance of the annual expansion factor was estimated following the method for the division of two independent variables (Equation 21; CTC 1999). The mean expansion factor and variance were estimated from the annual expansion factor estimates (Equations 20-25), and could be used to estimate escapement in future years (Equations 18 and 19). Approximate 95% confidence intervals were calculated with the normal approximation.

5. Results

5.1 Mark-Recapture Estimates

Mark-recapture estimates of escapement to the Nicola River were prepared for 1995 to 1999. Estimates presented for 1995 to 1998 are final estimates; those presented for 1999 are preliminary (Table 5.1). Complete summaries of the analyses for 1995 to 1998 are reported in the annual escapement reports for the Nicola River system (Farwell et al. 1999, reports for 1996-1999 are in preparation and available from the senior author). Escapement estimates are summarized in Table 5.1.

Mark-recapture escapement estimates ranged from 1,547 in 1998 to 17,777 in 1996. Estimates were precise, except for 1998: 95% confidence bounds ranged from +/- 10.22% to +/- 29.6%. Mean 95% confidence bounds were +/- 15.16%.

We assessed the representativeness of the sampling process by looking for bias in the temporal, spatial, fish size and sex composition patterns of the two application and recovery samples annually. Biases, other than sex were detected in two of four years' mark-recapture data, 1996 and 1997 (Appendix 2). No biases were detected in data for 1995 or 1998, and 1999 results are, as yet, preliminary. As previously stated, all analyses were stratified by sex. Significant impacts were observed in the temporal and spatial patterns in 1996 and 1997; however, in both cases the observed biases, although present in both samples, were in opposite directions. Based on the observation that the biases were not present in the same strata in both samples and that the detected biases were toward different portions of the

populations, we conclude the observed biases likely did not significantly bias the overall escapement estimates.

Escapements to Nicola River above Nicola Lake (Reach 1) were less than 25 for 1995 to 1998 (Upper Nicola Indian Band fence, unpublished data). However the fence was not installed in 1999 and we estimated from a single aerial survey of the upper river and the Spahomin channel fence count (tributary to Douglas Lake) that 199 chinook spawned in the Upper Nicola River and Spahomin channel. These fish were represented in the mark-recapture population estimate and were sampled for marks, but excluded from the aerial counts of the AUC-based estimates.

5.2 Aerial Enumeration

Enumeration flights were conducted on the Nicola drainage between September 5th and September 23rd, annually from 1995 to 1999. Reach counts for holding and spawning chinook, and carcasses are presented in Appendix 3.

For the replicated flights, spawner counts on flight 1 generally exceeded the counts on flight 2 for high spawner counts (>1000 fish; Figure 5.1). One outlier point was the result of the reach 4 flights on September 12, 1996 when the flight one count was substantially higher than the flight two count. In this case, the flight two crew flew that reach early in the morning, experienced significant light reflection problems due to the lower sun angle, and also, experienced considerable wind riffling of the surface, which had dissipated by the time the other crew arrived. The intraclass correlation coefficient (0.974) indicated the measurements were repeatable with about 3% of the variation occurring within daily reach counts. The deviations of the paired counts were not normally distributed (Kolmogorov-Smirnov, $Z = 0.223$, $P < 0.001$) and the paired counts were similar (Wilcoxin Signed Rank, $Z = -1.94$, $P = 0.053$).

5.2.1 Statistical Properties of Aerial Estimates

5.2.1.1 AUC

For all comparisons, the statistical bias of the bootstrap estimates was less than 0.17%, indicating the bootstrap approaches provided accurate estimates of AUC on average (Table 5.2). The regression and median CV methods for estimating the SD of daily reach counts provided differing estimates of variance in AUC. The regression method yielded smaller variance estimates at high AUC estimates than the median CV method, whereas the median CV method yielded lower variance estimates at low AUC estimates. Thus, the median CV method frequently yielded more conservative AUC variance estimates than the regression method.

The three parametric bootstrap approaches calculated similar AUC variance estimates, and neither approach produced consistently high or low variance estimates (Table 5.2). In 1996, five flights recorded spawner counts in seven reaches, accordingly bootstrap approaches 1 and 2 each involved 35 empirical distributions of spawner counts, whereas approach 3 involved five empirical distributions. Approaches 1 and 2 had more opportunities for random variation and may be more representative of the field data collection method. Approach 2 estimated AUC and variance for each reach

independently, then summed the reach AUC and variance estimates to calculate the total AUC and variance estimates. Approach 1 differed from approach 2 by summing the randomly resampled daily reach counts, then total AUC was calculated and variance was estimated from the distribution of total AUC estimates. Approach 1 better resembles the usual method for calculating AUC, and is therefore the most preferred method we examined.

5.2.1.2 Apparent Redd Residence

Apparent redd residence was determined for 1996 to 1999, by dividing the AUC estimate of total spawner-days by the Petersen escapement estimate. Apparent redd residence ranged from 5.34 d (1999) to 6.37 d (1998) with a mean (95% confidence interval) of 5.81 d (4.98-6.64 d; Table 5.3). The apparent redd residence estimates were very similar among years and precise, with CVs ranging from about 0.06 (1996 and 1997) to 0.16 (1998). Measurement error represented about 5% of the overall variation in the mean apparent redd residence.

The least squares estimate of apparent redd residence (95% confidence interval) was 5.67 d (5.50-5.85 d) and was not adjusted for measurement error of the mark-recapture or AUC estimates (Figure 5.3). The mean apparent redd residence had a larger error sum of squares than the least squares estimate, yet the mean apparent redd residence accurately estimated escapement when compared in retrospect to the annual mark-recapture escapement estimates (retrospective AUC; Figure 5.3). Annual escapement estimates from the mean apparent residence had biases ranging from –9% to +9%, and were within the 95% confidence limits of the mark-recapture escapement estimates.

5.2.1.3 Peak Count

The peak count expansion methodology generally produced lower chinook escapement estimates than the mark recapture methodology (Figure 5.3; Table 5.4). In years when several flights occurred, the peak count expansion adequately indexed the escapement and was sufficiently sensitive to indicate changes in the escapement abundance among the years examined. However, few flights occurred in 1995, following the usual peak count expansion methodology, and the peak count expansion method substantially underestimated escapement (RB = -51%). Raw peak counts varied from 719 (1998) to 10,975 (1996), and yielded expanded estimates ranging from 1,106 to 16,885 chinook.

The goodness-of-fit tests indicated the mark-recapture method estimated significantly higher escapements than the peak count expansion method for all years except 1996 (Figure 5.3). The methods were not statistically compared in 1995 because we were unable to estimate the variance of the peak count. The relative bias varied annually and corresponded with the goodness-of-fit tests with little bias in 1996 (-5%), but considerably more in other years (-17 to -32%; Table 5.4). Non-overlapping 95% confidence intervals identify meaningful differences between parameter estimates and avoid the assumptions of normality (Reichardt and Gollob 1997). Non-overlapping 95% confidence intervals indicated biologically significant differences in 1997 only, and did not detect differences between the escapement estimation methods in other years, despite the large apparent biases. The z-test (goodness-of-fit) was more powerful and sensitive than the confidence interval comparison, and indicated significant differences between methods in 1997, 1998, and 1999.

The peak count expansion escapement estimates were precise, with CVs ranging from about 0.05 (1996 and 1997) to 0.07 (1999), and the majority of estimated variation was contributed from variation in spawner counts, followed by holding fish, and carcasses (Table 5.4). The annual expansion factor estimates were variable among years and measurement error represented about 13% of the overall variation in the mean expansion factor.

6. Discussion

Escapement estimates for spring and summer run chinook salmon in the tributaries to the Fraser and Thompson rivers has traditionally been done with visual counts from helicopter overflights. In early years, often only one flight per year was undertaken on each tributary, however, the current program attempts to estimate escapement on two or three separate days, near the peak of spawning for each system. Estimates are then calculated based on expanded peak counts. The overflight program was initiated in the early 1970's and expanded to provide two or three flights per spawning system in 1989.

Visual estimates tend to be inaccurate and frequently underestimate population size (Tschaplinski and Hyatt 1991). The accuracy of aerial counts is influenced by the physical conditions at the time of counting. Light penetration, turbidity, fish behaviour and weather all influence fish visibility (Bevan 1961). Other factors influencing aerial estimates include the experience of the pilot and observers, flight scheduling and frequency of counts (Bevan 1961; Neilson and Geen 1981). We attempted to schedule aerial counts when observation conditions would be best and used helicopter pilots with prior experience in low level fish enumeration. The observers used during this study comprised of almost half of the observers used on overflight counts of chinook in the Fraser, and inter-observer differences in counts were, in almost all cases, very small.

An examination of data from replicate flights indicated the individual reach counts were precise. Paired estimates of abundance by reach, with the exception of one pair on reach four in 1996, were very similar. Time of flying individual strata can be critical for observing fish. Due to the length of the Nicola flight, and variable wind conditions (typically building during the day) in the valleys, flights started at 0930, and the second flight crew typically started their count at reach four. Flying downstream in reach four, at that time of day, may, under some light conditions, result in the observers having to count through considerable glare. The crew of flight one, who counted that reach over one hour later, when the sun was higher, experienced much less glare.

Flight two counts were almost always slightly lower than flight one counts. This is likely due to pilot experience. Flight one was always flown by the pilot who conducts all the flights on non-replicate days. He has extensive experience conducting fish counts and wildlife telemetry. Flight two pilots were experienced but had considerably less wildlife and fisheries experience than the flight one pilot. The lack of wildlife and fisheries experience was particularly evident in the positioning of the helicopter during counts of ox-bowed river sections. Poor positioning frequently results in fish moving into refuge cover from sections immediately adjacent to those being counted, before the fish were observed by the counters.

Salmon are seen and counted most easily when dispersed into shallow spawning ground areas at the peak of spawning (Cousens et al. 1982). Therefore, it is important to schedule flights to coincide with the peak of spawning, if peak counts are to be expanded to yield escapement estimates. In all years the escapement estimate derived from peak counts were negatively biased compared to the mark-recapture estimates, although the differences were not statistically significant in 1996 (goodness-of-fit test). The magnitude of the bias varied annually. Given these biases, it seems likely that chinook escapements to the Fraser Interior, assessed aerially are likely also biased low. Confidence intervals for the mark-recapture estimate and expanded peak counts however, failed to overlap only in 1997.

The mark-recapture method will produce an accurate estimate of the actual population size if the capture and tagging process do not significantly influence subsequent fish behaviour (Ricker 1975). A second important aspect to producing an accurate population estimate from the mark - recovery method is that the mark application and carcass recovery samples should be representative of the population (Ricker 1975). It is preferable for both samples to be taken in a random manner; however, if only one of the samples is random, the results are not biased (Robson 1969). Ricker (1975) points out that if both samples are biased in the same direction the mark-recapture estimate is negatively biased.

While some biases were identified in the analyses of the mark-recapture data (Farwell et al. 1999; Appendix 2), the biases were not replicated in the two samples. When a directional bias in an application sample stratum was not present, or was in an opposite direction in the equivalent recovery sample stratum we concluded that the mark-recapture estimate had not been directionally biased and that the population estimate was deemed acceptable. The estimates were precise for all years except 1998, when the estimated escapement was small.

Mark-recapture estimates were used to determine apparent redd residence times. Using observed spawner counts, and constructing AUCs for each year, the resultant estimates of redd residence were very consistent. The estimated mean residence time of 5.7 days was less than a radio-tag estimate of redd residence (~7 days) determined by Nicola Tribal Authority staff from tracks of 14 female chinook in 1997. This may be due to the small number of fish tracked, or more likely to tracking females only, since females tend to reside in the vicinity of the redd longer than males. Other approaches of determining representative estimates of redd residence should be evaluated.

AUC estimates require estimates of residence time. Further work is needed with other populations to determine residence times. Residence times could be determined with telemetry, tower observation data (where densities are lower) or from mark-recapture methods such as in this paper, Manske and Schwarz (2000) or Lady and Skalski (1998). In the Nechako River in the upper Fraser watershed, AUC estimates are generated using visually obtained estimates of redd residence. Observers positioned in observation towers or on platforms near the spawning area record redd residence times for individual females. This approach requires being able to accurately identify each individual fish by natural markings present on the external surfaces of the fish. This may be practical when spawner densities are low, however, when densities are high such as occurs some years in reaches 2 and 4 in the Nicola River, this may not be possible. Radio tracking is another possible approach, however, radio tagging is invasive, and may significantly alter fish behavior. Also, previous studies have typically focussed on females,

however, as previously stated, female redd residence is often longer than that of males, thus, AUC escapement estimates based solely on female residence information may be negatively biased.

The consistency of apparent redd residence estimates among years indicated more reliable escapement estimates may be obtained from an AUC method, as opposed to expanding peak counts. Given the problem of scheduling counts to coincide with peak spawning activity, and the variation observed in the expansion factor, peak count expansions should only be used when insufficient observations inhibit development of AUC escapement estimates. As we expected, the retrospective AUC escapement estimates, from AUC and the calculated mean residence time, yielded similar estimates to the mark-recapture method for each of the four years. While we recognize that this is somewhat circular, we intend to evaluate this approach (using the mean redd residence time determined here, and applying it to subsequent AUC estimates) at Nicola over the next two seasons to assess the utility and reliability of the method.

The choice of estimation technique is governed by several factors including budget, and requirements for precision and accuracy. Mark-recapture estimates, when designed appropriately and undertaken to sample a large portion of the spawning population, can yield precise population estimates, and estimates of escapement by age, sex, and CWT group. AUC-based visual methods may also yield relatively precise estimates, given appropriate estimates of redd residence, and sufficient observations to construct representative spawner curves. AUC estimates however, do not provide age and/or sex-specific escapement estimates, or CWT contribution rates.

Peak count expansions are estimates that adequately index abundance. However, the results of this study and others indicate that expanded peak count estimates tend to be biased low compared to other estimates. Peak count estimates do not provide estimated escapements by age and sex or estimates of CWT returns.

Although the scope of this study was insufficient to conclude the number of flights required to generate representative spawner curves, some generalizations can be made. In general, using AUC-based estimates, too few flights near the peak of spawning will result in under-estimation of the peak period, while insufficient flights near the tails of the run will result in over estimating numbers at the start and end of the runs. Although we present data for 5 or 6 flights per year in this study, the pattern of dates flown was initially chosen to provide a high likelihood of encountering the peak of spawning to permit evaluation of peak-count expansions. To evaluate the minimum number of flights required to construct representative spawner curves, we suggest undertaking work on systems that require less flight time per survey, and flying every other day throughout the spawning period. Then, those data could be sampled to determine the relationships between number of flights and the resultant performance of the AUC estimates.

To use these data to evaluate the impact of various flying schedules on peak count estimates is, again, unrealistic. In other systems, typically two or three flights are undertaken annually. The first flight is used to estimate the timing of the peak of spawning. Second flights are pre-scheduled to coincide with predicted peak of spawning, and the timing of the second flight may be adjusted if necessary, based on

the observations on flight 1. Third flights, when sufficient funds are available, are used to verify that significant numbers of "new fish" have not arrived on the spawning grounds, and that the second flight was indeed the peak flight. Third flights are typically carried out 4-7 days after flight 2.

Flights during this study were scheduled to occur at shorter intervals, in an attempt to ensure getting at least one flight very close to the peak of spawning. If the Nicola River was to be surveyed with three flights, they would be scheduled approximately on the 7th, 12th, and 17th of September. Again, to evaluate the impact of the various flying schedules on peak counts, and as with the AUC related research, we suggest undertaking work on systems that require less flight time per survey, and flying every other day throughout the spawning period. Then, those data could be sub-sampled to determine the relationships between numbers of flights, flight dates, and the resultant peak count expansions.

It is also not realistic to undertake cost-benefit analyses of the different methods based on these results. The Nicola River is a relatively long system, and each aerial survey requires about 3.5 hr airtime (~$2700 including fuel). Other systems with similar escapements require only 1.0 to 1.2 hr airtime per survey (~$1000 including fuel). Similarly, because of the different situations with the cost of labour to undertake mark-recaptures on both systems, such work is relatively inexpensive on the Nicola, but much more expensive on other systems, to achieve similar levels of estimate precision.

7. Conclusions

1. In the Nicola River, replicate aerial counts of spawning chinook were similar and repeatable. Differences were due chiefly to variable pilot experience and lighting.

2. Apparent redd residence times were relatively consistent over four years. In retrospect, their mean could be used to adequately estimate chinook escapements at the Nicola River.

3. In the Nicola River, expanded peak count estimates were typically biased low when compared to mark-recapture estimates, but the magnitude of the bias was inconsistent. Peak count expansion estimates are considered negatively biased indexes that performed reasonably well for monitoring chinook escapement trends.

4. Although we were unable to examine in detail all the factors that need to be considered in determining the number of overflights necessary to produce scientifically defensible AUC spawner escapement estimates, we suggest that at least four flights are required annually per system. With fewer flights, the possibility of missing the peak of spawning is too high and therefore resultant spawner curves may not adequately represent the escapement.

8. Recommendations

We recommend similar studies be conducted in other watersheds in order to examine:

1) the repeatability of aerial counts;
2) spatial and temporal variability in survey life;
3) degree of bias associated with aerial overflight-based estimates, and;
4) the relationship between the number of flights, their timing and the accuracy of resultant escapement estimates.

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11. Tables

Table 2.1 River segments and associated reach designations

River segment	Reach
Upper Nicola R. (above Nicola Lake)	1
Nicola River from Nicola Lake outlet to Coldwater River confluence	2
Lower 5 km of Coldwater River	3
Nicola River from Coldwater River confluence to Gavelin Bridge	4
Nicola River from Gavelin Bridge to Spius Creek confluence	5
Spius Creek below Little Box Canyon	6
Nicola River from Spius Creek confluence to lower Dot trestle	7
Nicola River from lower Dot trestle to mouth (Spences Bridge)	8

Table 4.1. Equations for calculating escapement estimates as part of the AUC methodology.

	Statistic		Estimated Variance	
Escapement Estimation	$\hat{N}_i = \frac{\hat{A}_i}{\bar{S}}$	(5)	$v(\hat{N}_i) \cong \hat{N}_i^2 \left[\frac{v(\hat{A}_i^*)}{\hat{A}_i^2} + \frac{v(\bar{S})}{\bar{S}^2} \right]$	(6)
Apparent Redd Residence	$\hat{S}_i = \frac{\hat{A}_i}{\hat{N}_{i,MR}}$	(7)	$v(\hat{S}_i) \cong \hat{S}_i^2 \left[\frac{v(\hat{A}_i)}{\hat{A}_i^2} + \frac{v(\hat{N}_{i,MR}^*)}{\hat{N}_{i,MR}^2} \right]$	(8)[1]
Mean Apparent Redd Residence	$\bar{S} \cong \bar{\hat{S}} = \frac{\sum_{i=1}^{k} \hat{S}_i}{k}$	(9)[2]	$v(\bar{S}) = v(\bar{\hat{S}}) - \hat{\sigma}^2$	(10)
			$v(\bar{\hat{S}}) = \frac{\sum_{i=1}^{k} (\hat{S}_i - \bar{\hat{S}})^2}{k-1}$	(11)[2]
Measurement Error	NA		$\hat{\sigma}^2 = \frac{\sum_{i=1}^{k} cv^2(\hat{S}_i)}{k}$	(12)[2,3]

1. The covariance of $\hat{A}_i$ and $\hat{N}_i$ equalled 0 because the two estimates were based on independent sampling programs.
2. k is the number of years with concurrent sampling programs.
3. $cv^2(\hat{S}_i)$ is the coefficient of variation of the apparent redd residence in year i squared.

Table 4.2. Equations for calculating the peak count escapement estimate, goodness-of-fit method, and relative bias.

	Statistic		Estimated Variance	
Escapement Estimation	$\hat{N}_{i,PK} = \hat{P}_i \times \pi$	(13)	$v(\hat{N}_{i,PK}) = \pi^2 \times v(\hat{P}_i)$	(14)
Peak Count Expansion Factor	$\pi = \frac{1}{0.65}$	(15)	NA	
Goodness-of-Fit Method	$z = \frac{\hat{N}_{i,MR} - \hat{N}_{i,PK}}{\sqrt{v(\hat{N}_{i,MR}) + v(\hat{N}_{PK})}}$	(16)	NA	
Relative Bias	$RB = \frac{\hat{N}_{i,PK} - \hat{N}_{i,MR}}{\hat{N}_{i,MR}}$	(17)	NA	

Table 4.3. Equations for calculating the mean peak count expansion factor.

	Statistic		Estimated Variance	
Escapement Estimation	$\hat{N}_{i,PK} = \hat{P}_i \times \overline{\pi}$	(18)	$v(\hat{N}_{i,PK}) = \hat{P}_i^2 \times v(\overline{\pi}) + \overline{\pi}^2 \times v(\hat{P}_i) - v(\overline{\pi}) \times v(\hat{P}_i)$	(19)
Peak Count Expansion Factor	$\hat{\pi}_i = \frac{\hat{N}_{i,MR}}{\hat{P}_i}$	(20)	$v(\hat{\pi}_i) \cong \hat{\pi}_i^2 \left[\frac{v(\hat{N}_{i,MR})}{\hat{N}_{i,MR}^2} + \frac{v(\hat{P}_i^*)}{\hat{P}_i^2} \right]$	(21)[1]
			$v(\overline{\pi}) = v(\overline{\hat{\pi}}) - \hat{\sigma}^2$	(22)
Mean Expansion Factor	$\overline{\pi} \cong \overline{\hat{\pi}} = \frac{\sum_{i=1}^{k} \hat{\pi}_i}{k}$	(23)[2]	$v(\overline{\hat{\pi}}) = \frac{\sum_{i=1}^{k} (\hat{\pi}_i - \overline{\hat{\pi}})^2}{k-1}$	(24)[2]
Measurement Error	NA		$\hat{\sigma}^2 = \frac{\sum_{i=1}^{k} cv^2(\hat{\pi}_i)}{k}$	(25)[2,3]

1. The covariance of $\hat{N}_i$ and $\hat{P}_i$ equalled 0 because the two estimates were based on independent sampling programs.
2. k is the number of years with concurrent sampling programs.
3. $cv^2(\hat{\pi}_i)$ is the coefficient of variation of the expansion factor in year i squared.

Table 5.1. Chinook escapement estimates with 95% confidence limits derived from mark-recapture methods, 1995 to 1999[1].

Year	Petersen Estimate	95% Confidence Limits Upper	Lower
1995	10,624	12,002	9,247
1996	17,777	19,594	15,961
1997	9,612	10,668	8,556
1998	1,547	2,005	1,089
1999	8,475	9,345	7,569

Table 5.2. AUC and variance estimates calculated with three parametric bootstrap approaches and SD calculated from regression and median CV methods.

Count SD Estimation	Bootstrap Approach	Parameter	Year 1996	1997	1998	1999
		AUC ($\hat{A}$; fish-days)	101211	56010	9847	45263
Regression	1	Variance	$4.03*10^6$	$1.62*10^6$	$1.76*10^5$	$1.24*10^6$
		CV	0.020	0.023	0.043	0.025
		Statistical Bias (%)	0.02	-0.12	-0.06	-0.07
	2	Variance	$4.27*10^6$	$1.63*10^6$	$1.69*10^5$	$1.19*10^6$
		CV	0.020	0.023	0.042	0.024
		Statistical Bias (%)	0.02	-0.12	-0.07	-0.07
	3	Variance	$4.07*10^6$	$1.41*10^6$	$1.52*10^5$	$1.34*10^6$
		CV	0.20	0.021	0.040	0.026
		Statistical Bias (%)	0.01	-0.03	0.06	-0.15
Median CV	1	Variance	$8.16*10^6$	$2.17*10^6$	$1.14*10^5$	$1.95*10^6$
		CV	0.028	0.026	0.034	0.031
		Statistical Bias (%)	0.13	-0.01	0.13	-0.01
	2	Variance	$9.06*10^6$	$2.11*10^6$	$1.23*10^5$	$2.03*10^6$
		CV	0.030	0.026	0.036	0.032
		Statistical Bias (%)	0.13	-0.01	0.13	-0.01
	3	Variance	$9.83*10^6$	$2.10*10^6$	$1.15*10^5$	$2.15*10^6$
		CV	0.031	0.026	0.035	0.032
		Statistical Bias (%)	-0.17	-0.13	0.04	-0.06

[1] Estimates of escapement to Nicola River below Nicola Lake. Escapement to Nicola River above Nicola Lake were less than 25 for 1995 to 1998 (Upper Nicola Indian band fence), however the fence was not installed in 1999 and we estimate from a single aerial survey of the upper river and the Spahomin channel fence that 199 chinook spawned in the Upper Nicola and Spahomin channel. These fish were part of the M/R estimated population and sampled for marks.

Table 5.3. Annual and mean apparent redd residence and variance estimates.

	Year			
	1996	1997	1998	1999
Apparent Redd Residence ($\hat{S}_i$; days)	5.69	5.83	6.37	5.34
Variance ($v(\hat{S}_i)$)	0.114	0.130	0.972	0.109
Mean Apparent Redd Residence ($\overline{\hat{S}}$; days)		5.81		
Variance ($v(\overline{S})$)		0.172		
95% Confidence Interval		4.98 – 6.64		

Table 5.4. Annual peak count expansion escapement and variance estimates, annual expansion factors and variance, and the mean expansion factor and variance.

	Year				
	1995	1996	1997	1998	1999
Peak Count ($\hat{P}_i$)	3400	10975	4241	719	4552
Escapement Estimate ($\hat{N}_i$)	5231	16885	6525	1106	7003
Variance	NA	$8.60*10^5$	$1.05*10^5$	4215	$2.24*10^5$
Relative Bias	-51%	-5%	-32%	-29%	-17%
Bootstrap Variance Estimate					
Spawner Counts	NA	$3.34*10^5$	$4.37*10^4$	1767	$7.08*10^4$
Holding Fish Counts	NA	$2.87*10^4$	106	4	$2.39*10^4$
Carcass Counts	NA	101	544	10	16
Total	NA	$3.67*10^5$	$4.43*10^4$	1781	$9.47*10^4$
Expansion Factor ($\hat{\pi}_i$)	3.12	1.62	2.27	2.15	1.86
Variance ($v(\hat{\pi}_i)$)	NA	0.015	0.029	0.122	0.086
Mean Expansion Factor ($\overline{\pi}$)[1]			1.97		
Variance ($v(\overline{\pi})$)[1]			0.074		
95% Confidence Interval[1]			1.43 – 2.52		

1. 1995 data were excluded from the mean expansion factor estimates because variance of the peak count expansion estimate was not estimated. Also, reach 8 and part of reach 3 were not surveyed in 1995.

12. Figures

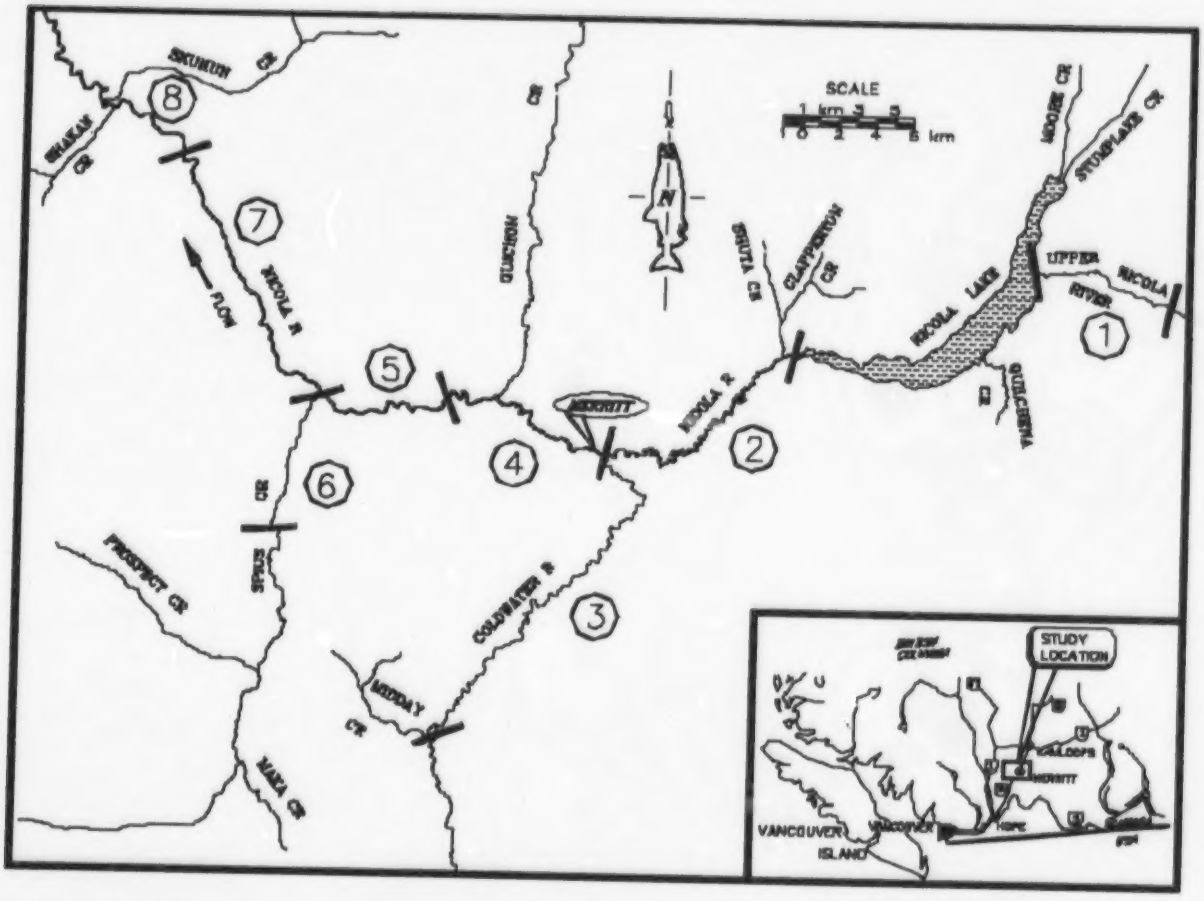

Figure 2.1. Study area map and reach locations in the Nicola and Coldwater rivers and Spius Creek

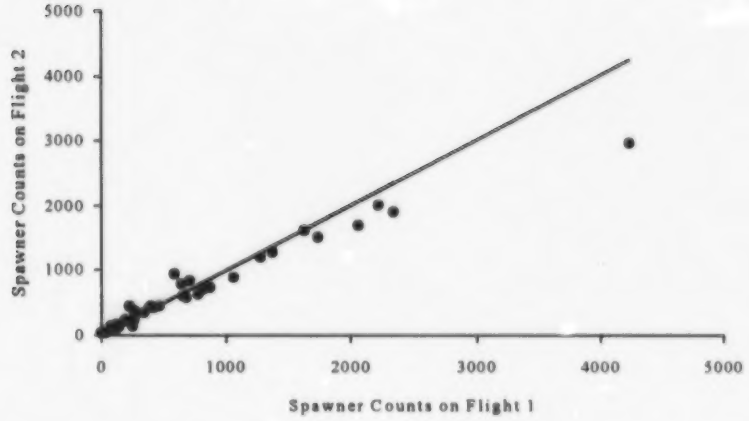

Figure 5.1. Spawner counts on flights 1 and 2 for Nicola River reaches, with the solid line indicating equality (n=42).

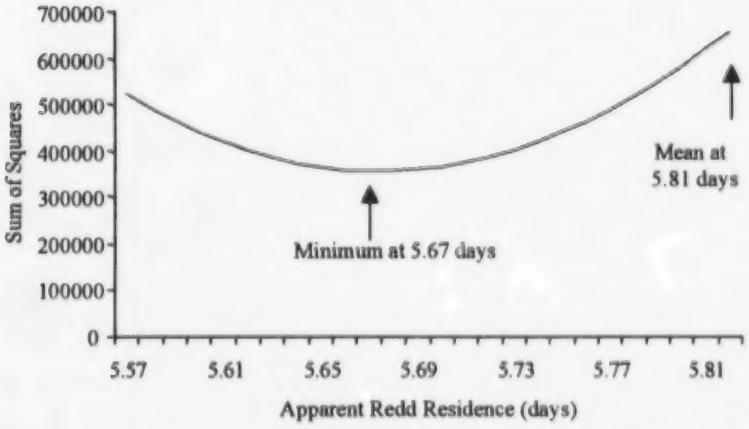

Figure 5.2. Least squares (minimum) and mean apparent redd residence estimates.

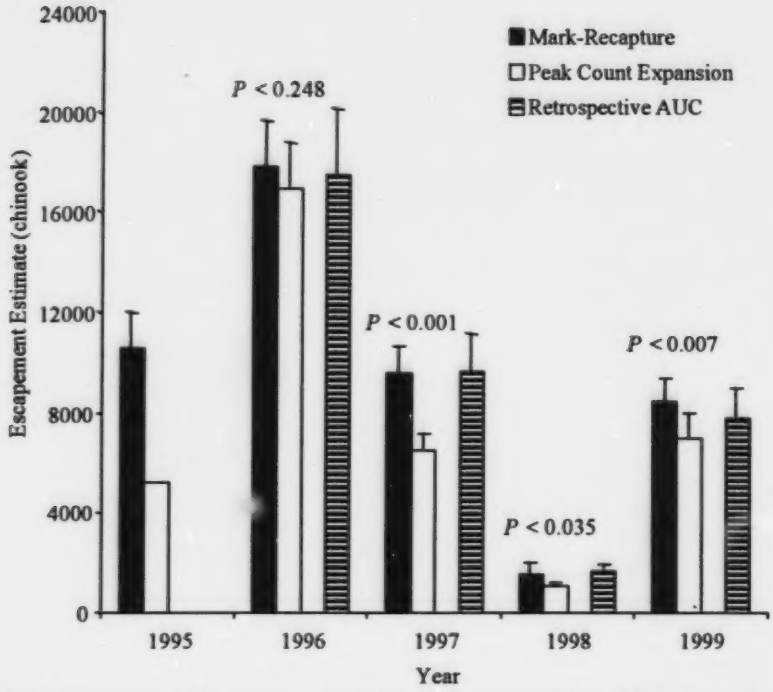

Figure 5.3. Mark-recapture, peak count expansion and retrospective AUC estimates of chinook escapement to Nicola River, 1995 to 1999, with upper 95% confidence limits and z-test *P*-values.[2]

[2] z-test *P*-values are for comparisons of mark-recapture and peak count expansion estimates only (1996-1999). In 1995, variance was not estimated for the peak count expansion, and reach 8 and part of reach 3 were not surveyed.

13. Appendices

13.1 Appendix 1 - Methods for estimating the SD of spawner counts for reaches of the Nicola River

Two replicate flights in 1996, 1997, and 1999 provided paired counts of chinook spawners for seven reaches of the Nicola River (42 paired counts). From the paired counts the mean, SD, and CV were calculated to describe the variance of the measurements. Similar to the results of Bevan (1961), there was increasing variability in SD at higher mean spawner counts and the linear relationship's residuals had a heteroscedastic distribution. To correct for this the data were transformed ($\log_{10}$). The mean was a good predictor of the SD (ANOVA, $F = 50.16$, $P < 0.001$; $R^2 = 0.55$; Figure 13.1) and the slope of the relationship was similar among years (ANCOVA, $F = 1.89$, $P = 0.165$) and reaches (ANCOVA, $F = 1.89$, $P = 0.323$). The relationship's residuals formed a horizontal band with no apparent pattern when plotted with Log (mean spawner count). The CV was variable at low spawner counts (Figure 13.2), thus mean spawner counts were partitioned into quartiles to describe the median and mean CV (Table 13.1). The median CV was more representative and a better estimate of the variation for spawner counts within quartiles than the mean CV, since it was less influenced by extreme values.

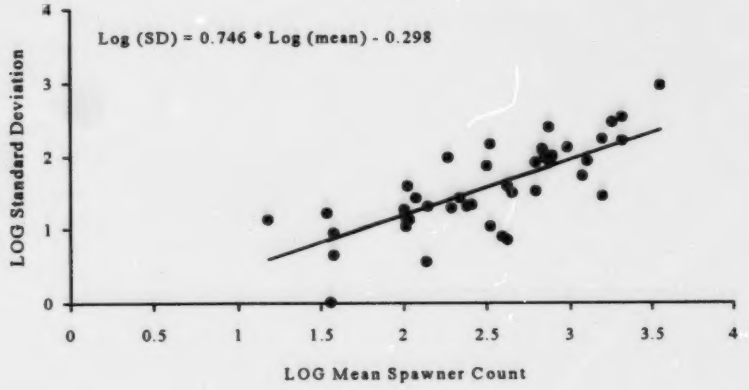

Figure 13.1. Relationship between the mean and standard deviation for paired spawner counts (n=42).

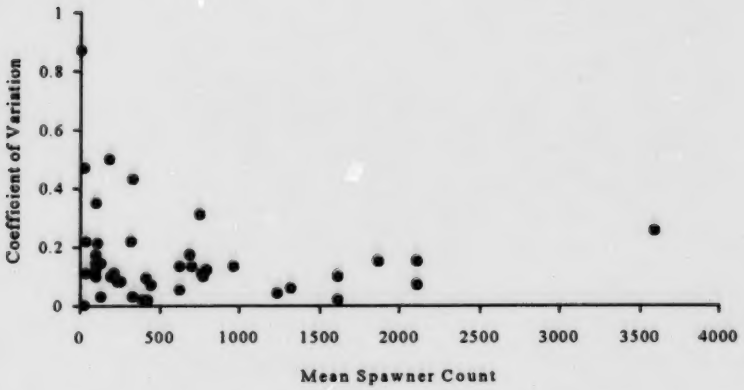

Figure 13.2. Coefficients of variation for the mean spawner counts from replicate flights (n=42).

Table 13.1. The median and mean coefficients of variation (CV) for quartiles of mean spawner counts from replicate flights.

	Quartile			
Parameter	1 - 121 Spawners	122 - 341 Spawners	342 - 779 Spawners	780 - 4240 Spawners
Median	0.1742	0.1056	0.1045	0.1098
Mean	0.2516	0.1726	0.1077	0.1103
n	11	10	11	10

In addition to spawner counts, the replicate flights provided paired counts of holding chinook. The CV was highly variable across holding chinook counts (Figure 13.3), thus mean holding chinook counts were partitioned into quartiles to describe the median and mean CV (Table 13.2). The median CV was more representative and a better estimate of the variation for holding chinook counts within quartiles than the mean CV, since it was less influenced by extreme values.

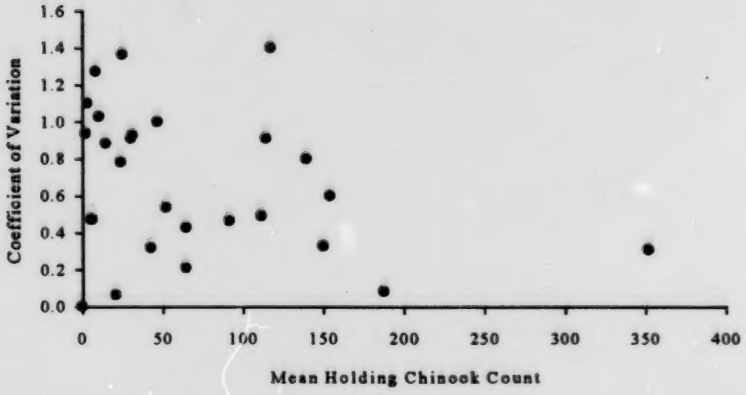

Figure 13.3. Coefficients of variation for the mean counts of holding chinook from replicate flights (n=42).

Table 13.2. The median and mean coefficients of variation (CV) for quartiles of mean holding chinook counts from replicate flights.

	Quartile			
Parameter	1 - 11 Holding Fish	12 - 32 Holding Fish	33 - 112 Holding Fish	113 - 430 Holding Fish
Median	1.4142	0.9428	0.4612	0.6061
Mean	1.1283	0.8563	0.5002	0.3134
n	7	6	7	7

The replicate flights provided paired counts of chinook carcasses. The study design was intended to examine the repeatability in spawner not carcass counts, therefore the timing of replicate flights resulted in a high frequency of paired counts when few carcasses were evident. The CV was variable across carcass counts (Figure 13.4), thus mean carcass counts were partitioned into quartiles to describe the median and mean CV (Table 13.3). The median CV was more representative and a better estimate of the variation for carcass counts within quartiles than the mean CV, since it was less influenced by extreme values.

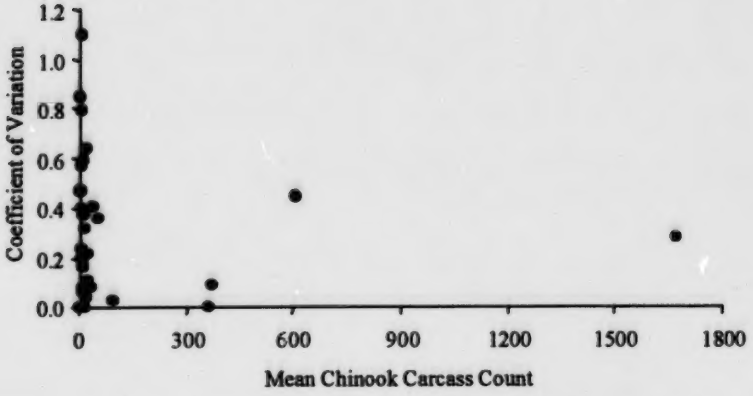

Figure 13.4. Coefficients of variation for the mean carcass counts from replicate flights (n=42).

Table 13.3. The median and mean coefficients of variation (CV) for quartiles of mean carcass counts from replicate flights.

Parameter	Quartile			
	1 - 3 Carcasses	4 - 9 Carcasses	10 - 19 Carcasses	20 - 3672 Carcasses
Median	1.0102	0.2662	0.1259	0.2263
Mean	0.9132	0.3093	0.2103	0.2478
n	10	10	10	11

13.2 Appendix 2 – Results of bias testing in Petersen mark-recapture estimates from 1995 to 1998[3]

Appendix 2.1. Results of statistical tests for bias in the 1995 Nicola River chinook salmon escapement estimation study. [1]

Bias Type	Application Sample	Recovery Sample
Statistical [2]	n/a	No bias detected
Period	No bias detected	No bias detected
Location	No bias detected	No bias detected
Fish size	No bias detected	No bias detected
Fish sex	No bias detected	No bias detected

Appendix 2.2. Results of statistical tests for bias in the 1996 Nicola River chinook salmon escapement estimation study. [1]

Bias Type	Application Sample	Recovery Sample
Statistical [2]	n/a	No bias detected
Period	Bias to early period in females	Bias to late periods in both sexes
Location	Bias to lower strata in both sexes	Bias to upper strata in both sexes
Fish size	No bias detected	No bias detected
Fish sex	Bias to females	No bias detected

Appendix 2.3. Results of statistical tests for bias in the 1997 Nicola River chinook salmon escapement estimation study. [1]

Bias type	Application sample	Recovery Sample
Statistical [2]	n/a	No bias detected
Period	Bias to early period in both sexes	Bias to late periods in females
Location	Bias to upper reaches in females	Bias to lower reaches in both sexes
Fish size	No bias detected	No bias detected
Fish sex	No bias detected	No bias detected

Appendix 2.4. Results of statistical tests for bias in the 1998 Nicola River chinook salmon escapement estimation study. [1]

Bias type	Application Sample	Recovery Sample
Statistical [2]	n/a	No bias detected
Period	No bias detected	No bias detected
Location	No bias detected	No bias detected
Fish size	No bias detected	No bias detected
Fish sex	No bias detected	No bias detected

[3] 1. No bias detected; undetected bias may be present. 2. Bias present when recoveries total 4 or less.

13.3 Appendix 3 - Reach counts of holding, spawning and dead chinook salmon estimated during overflight surveys from 1996 – 1999.

13.3.1 Appendix 3.1 "Best" counts of holding and spawning fish, and carcasses, estimated from overflights, in 1996

		Reach							
Date		2	3	4	5	6	7	8	Totals
05-Sep	live	105	305	1,036	377	34	1,071	102	3,030
	dead	2	1	3	3	0	8	1	18
	total	107	306	1,039	380	34	1,079	103	3,048
	hold[1]	70	204	694	253	23	718	68	2,030
	spawn[1]	35	101	342	124	11	353	34	1,000
		105	305	1,036	377	34	1,071	102	
09-Sep	holding	101	249	1,035	190	47	793	102	2,517
	spawning	1,287	657	2,646	949	55	385	101	6,080
	dead	3	1	3	0	2	6	2	17
	total	1,391	907	3,684	1,139	104	1,184	205	8,614
12-Sep	holding	45	4	235	49	4	190	52	579
flight 1	spawning	2,067	1,276	4,240	1,733	81	642	259	10,298
	dead	10	29	26	18	2	10	3	98
	total	2,122	1,309	4,501	1,800	87	842	314	10,975
12-Sep	holding	85	0	0	0	0	40	10	135
flight 2	spawning	1,675	1,202	2,950	1,506	134	771	231	8,469
	dead	10	21	22	11	6	13	2	85
	total	1,770	1,223	2,972	1,517	140	824	243	8,689
18-Sep	holding	0	0	0	0	0	0	0	0
flight 1	spawning	654	399	1,637	596	23	235	253	3,797
	dead	350	361	2,000	800	18	92	50	3,671
	total1	1,004	760	3,637	1,396	41	327	303	7,468
18-Sep	holding	0	0	0	0	0	0	0	0
flight 2	spawning	607	451	1,597	929	46	441	120	4,191
	dead	396	363	1,345	420	19	96	27	2,666
	total2	1,003	814	2,942	1,349	65	537	147	6,857
23-Sep	holding	0	0	0	0	0	0	0	0
	spawning	203	64	352	206	5	192	68	1,090
	dead	333	286	820	276	15	99	21	1,850
	total	536	350	1,172	482	20	291	89	2,940

[1] Holding and spawning fish on first flight estimated from field notes of ratio of holders and spawners

13.3.2 Appendix 3.2 "Best" counts of holding and spawning fish, and carcasses, estimated from overflights, in 1997

Date		Stratum 2	3	4	5	6	7	8	Totals
5-Sep	holding	47	62	305	193	169	325	0	1101
	spawning	88	102	147	108	68	36	2	551
	dead	3	4	2	0	5	1	0	15
	total	138	168	454	301	242	362	2	1667
9-Sep flight 1	holding	177	73	274	88	115	62	7	796
	spawning	391	206	1063	683	97	276	6	2722
	dead	1	4	9	2	4	1	0	21
	total	569	283	1346	773	216	339	13	3539
9-Sep flight 2	holding	197	32	430	220	185	122	0	1186
	spawning	402	242	883	571	112	246	25	2481
	dead	6	8	7	3	8	0	0	32
	total	605	282	1320	794	305	368	25	3699
12-Sep flight 1	holding	18	4	10	0	53	3	0	88
	spawning	872	435	1381	721	126	272	32	3839
	dead	6	7	33	15	6	11	2	80
	total	896	446	1424	736	185	286	34	4007
12-Sep flight 2	holding	2	9	37	17	33	7	0	105
	spawning	735	425	1266	836	154	372	44	3832
	dead	11	10	37	15	16	10	3	102
	total	748	444	1340	868	203	389	47	4039
15-Sep	holding	0	0	0	0	14	0	0	14
	spawning	960	447	1359	791	129	283	43	4012
	dead	25	24	86	40	18	21	1	215
	total	985	471	1445	831	161	304	44	4241
19-Sep	holding	0	0	0	0	0	0	0	0
	spawning	817	260	730	405	44	180	60	2496
	dead	73	47	228	114	13	30	1	506
	total	890	307	958	519	57	210	61	3002

13.3.3 Appendix 3.3 "Best" counts of holding and spawning fish, and carcasses, estimated from overflights, in 1998

		Stratum							
Date		2	3	4	5	6	7	8	Totals
5-Sep	holding	3	9	9	0	11	69	2	103
	spawning	0	0	6	0	7	0	0	13
	dead	2	0	0	1	0	1	0	4
	total	5	9	15	1	18	70	2	120
9-Sep	holding	1	6	0	7	8	98	0	120
	spawning	2	0	17	14	10	6	0	49
	dead	0	0	0	0	0	0	0	0
	total	3	6	17	21	18	104	0	169
12-Sep	holding	0	3	4	2	1	18	6	34
	spawning	46	3	63	49	8	26	0	195
	dead	1	0	0	0	2	0	0	3
	total	47	6	67	51	11	44	6	232
15-Sep	holding	2	3	0	0	1	26	22	54
	spawning	124	0	179	110	9	71	7	500
	dead	0	0	0	2	0	3	0	5
	total	126	3	179	112	10	100	29	559
19-Sep	holding	0	2	0	0	0	0	0	2
	spawning	137	0	288	163	2	90	22	702
	dead	2	0	4	7	0	2	0	15
	total	139	2	292	170	2	92	22	719
23-Sep	holding	0	0	0	0	0	0	0	0
	spawning	88	1	204	145	0	99	23	560
	dead	3	0	13	8	1	5	0	30
	total	91	1	217	153	1	104	23	590

13.3.4 Appendix 3.4 "Best" counts of holding and spawning fish, and carcasses, estimated from overflights, in 1999

Date		Stratum 2	3	4	5	6	7	8	Totals
5-Sep	holding	613	12	687	40	326	243	4	1925
	spawning	43	58	97	201	52	48	0	499
	dead	1	1	2	0	0	2	0	6
	total	657	71	786	241	378	293	4	2430
9-Sep	holding	449	0	150	0	129	108	2	838
	spawning	1130	87	575	394	105	132	5	2428
	dead	3	3	7	1	0	0	0	14
	total	1582	90	732	395	234	240	7	3280
12-Sep	holding	220	0	80	0	150	55	5	510
flight 1	spawning	2228	142	821	477	182	120	36	4006
	dead	5	7	6	6	7	4	1	36
	total	2453	149	907	483	339	179	42	4552
12-Sep	holding	60	0	13	0	72	74	25	244
flight 2	spawning	2005	137	706	434	209	101	36	3628
	dead	2	8	1	4	0	4	0	19
	total	2067	145	720	438	281	179	61	3891
15-Sep	holding	50	0	0	0	20	0	0	70
flight 1	spawning	2350	138	781	348	114	114	41	3886
	dead	68	16	31	13	18	11	0	157
	total	2468	154	812	361	152	125	41	4113
15-Sep	holding	10	0	0	0	22	0	0	32
flight 2	spawning	1886	102	616	333	89	94	35	3155
	dead	40	16	11	7	10	8	3	95
	total	1936	118	627	340	121	102	38	3282
19-Sep	holding	0	0	0	0	15	0	0	15
	spawning	549	48	348	132	36	73	34	1220
	dead	250	100	21	280	100	18	20	789
	total	799	148	369	412	151	91	54	2024